Centre for
Climate Change
Economics and Policy

An ESRC Research Centre

Grantham Research Institute on
Climate Change and
the Environment

What will global annual emissions of greenhouse gases be in 2030, and will they be consistent with avoiding global warming of more than 2°C?

Rodney Boyd, Nicholas Stern and Bob Ward

Policy paper

May 2015

ESRC Centre for Climate Change Economics and Policy

Grantham Research Institute on Climate Change and the Environment

Global
Green Growth
Institute

UNIVERSITY OF LEEDS

The ESRC Centre for Climate Change Economics and Policy (CCCEP) was established in 2008 to advance public and private action on climate change through rigorous, innovative research. The Centre is hosted jointly by the University of Leeds and London School of Economics and Political Science. It is funded by the UK Economic and Social Research Council. More information about the ESRC Centre for Climate Change Economics and Policy can be found at: http://www.cccep.ac.uk

The Grantham Research Institute on Climate Change and the Environment was established in 2008 at London School of Economics and Political Science. The Institute brings together international expertise on economics, as well as finance, geography, the environment, international development and political economy, to establish a world-leading centre for policy-relevant research, teaching and training about climate change and the environment. It is funded by the Grantham Foundation for the Protection of the Environment, which also funds the Grantham Institute - Climate Change and the Environment at Imperial College London. More information about the Grantham Research Institute can be found at: http://www.lse.ac.uk/grantham/

The Authors
Rodney Boyd is a Policy Analyst and Research Advisor to Nicholas Stern at the Grantham Research Institute on Climate Change and the Environment and the ESRC Centre for Climate Change Economics and Policy at London School of Economics and Political Science.

Nicholas Stern is Chair of the Grantham Research Institute on Climate Change and the Environment and the ESRC Centre for Climate Change Economics and Policy at London School of Economics and Political Science, and President of the British Academy.

Bob Ward is Policy and Communications Director at the Grantham Research Institute on Climate Change and the Environment and the ESRC Centre for Climate Change Economics and Policy at London School of Economics and Political Science.

Acknowledgements
The authors are grateful to Alina Averchenkova, Fergus Green and Emmanuel Guérin for assisting us in various ways during the preparation of this paper.

What will global annual emissions of greenhouse gases be in 2030, and will they be consistent with avoiding global warming of more than 2°C?

Rodney Boyd, Nicholas Stern and Bob Ward

May 2015

Introduction

Parties to the United Nations Framework Convention on Climate Change (UNFCCC) agreed at the 20th session of the Conference of the Parties (COP20) in Lima, Peru, in December 2014 to set out their "intended nationally determined contributions" (INDCs) during the first quarter of 2015, ahead of COP21 in Paris, France, in December 2015. These INDCs are expected to include an indication of expected annual emissions beyond 2020 (many Parties provided information about their annual emissions in 2020 following COP15 in Copenhagen, Denmark, in December 2009). As of 30 April 2015, 35 countries, including the 28 Member States of the European Union, have submitted INDCs[1]. In addition, China has already provided some indication of what may be included in its INDC. This note describes the preliminary calculation of what global annual emissions in 2030 could be, based on the INDCs and announcements by some of the largest emitters: the European Union, the United States and China. This calculation is compared with published emissions pathways that are consistent with the international goal of avoiding global warming of more than 2°C[2].

Our conclusions are provided in the final section of this paper. We think that it is important to offer a preliminary analysis of how the pledges and announcements by some of the biggest emitters, together with assumptions about current and planned policies by other countries, compare against pathways for staying within the global warming limit of 2°C. This allows us to confirm that there is a gap between the emissions pathway that would result from current ambitions and plans, and a pathway that is consistent with the global warming limit of 2°C. Consequently, countries should be considering opportunities to narrow the gap before and after the Paris summit.

[1] INDCs that have been submitted to the secretariat of the UNFCCC are published at: http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx

[2] The report from COP16 in Cancún, Mexico, in 2010 (UNFCCC, 2011), states: "The Conference of the Parties…Further recognizes that deep cuts in global greenhouse gas emissions are required according to science, and as documented in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, with a view to reducing global greenhouse gas emissions so as to hold the increase in global average temperature below 2 °C above preindustrial levels, and that Parties should take urgent action to meet this long-term goal, consistent with science and on the basis of equity".

Method

Over the past six months, the European Union, United States and China, which together are responsible for almost half of current annual emissions of greenhouse gases, have each made pledges and announcements about their future annual emissions, over and above what they have announced previously.

On 23 October 2014, the European Council (2014) endorsed a binding collective target for the 28 Member States of the European Union of "at least 40% domestic reduction in greenhouse gas emissions by 2030 compared to 1990". This commitment was embodied in the INDC which the Government of Latvia and the European Commission submitted on behalf of the European Union and its Member States to the secretariat of the UNFCCC in March 2015.

In addition, on 12 November 2014, President Barack Obama and President Xi Jinping released a 'U.S.-China Joint Announcement on Climate Change' (Office of the White House Press Secretary, 2014). It stated:

"Today, the Presidents of the United States and China announced their respective post-2020 actions on climate change, recognizing that these actions are part of the longer range effort to transition to low-carbon economies, mindful of the global temperature goal of 2°C. The United States intends to achieve an economy-wide target of reducing its emissions by 26%–28% below its 2005 level in 2025 and to make best efforts to reduce its emissions by 28%. China intends to achieve the peaking of CO_2 emissions around 2030 and to make best efforts to peak early and intends to increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030. Both sides intend to continue to work to increase ambition over time."

The commitment by the United States was embodied in its INDC, which was submitted to the secretariat of the UNFCCC in March 2015.

These announcements and INDCs have been analysed, together with information about annual greenhouse gas emissions published by authoritative sources, including the International Energy Agency, the European Environment Agency and the United States Environmental Protection Agency. We consider the basket of six anthropogenic greenhouse gases covered by the Kyoto Protocol (i.e. carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride), and express the size of emissions in terms of gigatonnes (Gt), or billions of metric tons, of carbon-dioxide-equivalent (CO_2e), based on 100-year global warming potentials. Estimates of country emissions include land use, land use change and forestry, and, for each country except Member States of

the European Union and the United States, include peat. Global emissions include international bunkers.

Our analysis splits countries into two groups: EU-US-China and the rest of the world. We use currently available information about past emissions for each of the EU-US-China group and make projections for their emissions in 2030 based on the recent announcements and 'intended nationally determined contributions'.

For the European Union, we have simply calculated emissions in 2030 by reducing by 40% the figure for emissions in 1990 of the 28 Member States, as published by the European Environment Agency. For the United States, we have projected emissions in 2030 by extrapolating from the emissions in 2025, calculated to be 28% lower than the figure for 2005, as published by the Environmental Protection Agency (see Appendix for details). For China, we have produced two estimates for its emissions in 2030 based on projections of totals published by the International Energy Agency for the period between 2010 and 2013. One projection assumes that annual emissions will peak by 2030 (i.e. the rate of increase in annual emissions declines gradually to zero in 2030), and the other assumes the peak is reached by 2025. The latter projection assumes that the peak is followed by a period of year-on-year decreases in annual emissions that mirror the increases between 2020 and 2025.

For the rest of the world, we use estimates of energy-related carbon dioxide emissions published by the International Energy Agency for an emissions scenario based on existing national policies and measures, including policies that are planned but not yet implemented (New Policies Scenario; see Appendix for details). These do not take account of the INDCs submitted by Switzerland, Norway, Mexico, Gabon, Russia and Liechtenstein, which were submitted to the secretariat of the UNFCCC by 30 April 2015.

The emissions totals for 2030 are compared with a synthesis by the United Nations Environment Programme (UNEP, 2014) of published estimates of emissions pathways (available in the database assembled by Working Group III of the Intergovernmental Panel on Climate Change for the Fifth Assessment Report) that are considered to be consistent with the internationally agreed goal of avoiding a rise in global mean surface temperature of more than 2°C.

It is important to note the uncertainties involved in making projections of future emissions. For instance, there are indications that China's annual emissions of greenhouse gases may peak even before 2025, as its consumption of coal, a major source of carbon dioxide emissions, was 2.9% lower in 2014 compared with 2013. Further details about the method are presented in the Appendix.

Results of preliminary analysis

The projected emissions of the European Union, United States and China in 2030 are presented in Table 1. We estimate that the collective annual emissions from this group were 21.1 Gt CO_2e in 2010 (Table 1). The emissions from this group are projected to be 22.3 Gt CO_2e in 2030 in the case where China's annual emissions peak in 2030, and 20.9 CO_2e in 2030 if the peak is in 2025.

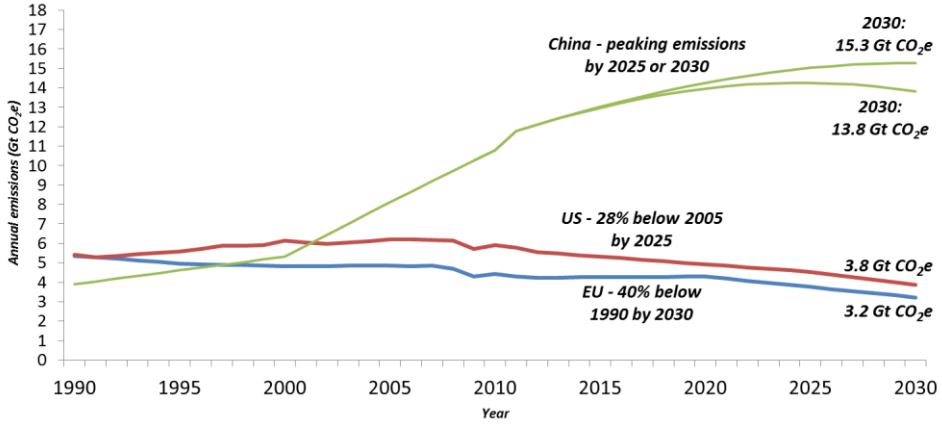
Table 1: Annual emissions to 2030 for the European Union, United States and China

Emitter (announced pledges)	**Annual emissions (Gt CO_2e)**			
	1990	**2005**	**2010**	**2030**
EU (40% below 1990 levels by 2030)	5.4	4.9	4.4	3.2
US (28% below 2005 levels by 2025)	5.4	6.2	5.9	3.8
China (peaking emissions by 2025)	-	-	10.8	13.8
China (peaking emissions by 2030)				15.3
Total (EU-US-China)*	**-**	**-**	***21.1***	***20.9–22.3***

*Note: columns and rows may not add up due to rounding.

The emissions pathways between 1990 and 2030 assumed by our analysis are illustrated in Figure 1.

Figure 1: Annual emissions between 1990 and 2030 for the European Union, United States and China



Using the New Policies Scenario published by the International Energy Agency, we estimate that annual emissions by the rest of the world (i.e. not including the 28 Member States of the European Union, United States and China) will increase from 26.2 Gt CO_2e in 2010 to 35.4 Gt CO_2e in 2030 (Table 2; see Appendix for details of method). These preliminary estimates do not take into account further action indicated by the rest of the world in INDCs that will be submitted to the UNFCCC secretariat during 2015, and which are expected to mean further emissions reductions beyond those achieved by existing policies.

Table 2: Annual emissions to 2030 for the rest of the world (i.e. not including European Union, United States and China)

Emitter	Annual emissions (Gt CO_2e)	
	2010	2030
Africa	4.7	7.0
Brazil	1.6	2.3
India	2.8	5.1
Asia (without China, India)	5.0	8.2
OECD Asia Oceania	2.7	2.2
Non-OECD Americas (without Brazil)	1.5	1.9
OECD Americas (without US)	1.5	1.3
Non-EU28 Europe/Eurasia	4.4	4.7
Middle East	2.1	2.7
Total (Rest of the World)	***26.2***	***35.4***

*Note: columns and rows may not add up due to rounding.

A comparison of the figures in Table 1 and Table 2 shows that the European Union, United States and China collectively produced 45% of global annual emissions of greenhouse gases in 2010. We project in 2030 that this group will be responsible for 39% of annual global emissions, if China's emissions peak in 2030, or 37% if they peak in 2025. Overall, global annual emissions rise from 48.5 Gt CO_2e in 2010 to between 57 and 59 Gt CO_2e in 2030, depending on when China's emissions peak (Table 3).

Table 3: Annual emissions to 2030

Emitter	Annual emissions (Gt CO_2e)		
	2010	2030 (*China's emissions peak in 2025)*	2030 *(China's emissions peak in 2030)*
Total country emissions	***47.4***	***56.2***	***57.7***
…international bunkers	*1.1*	*1.3*	*1.3*
Total global emissions	***48.5***	***57.6***	***59.0***
Total (EU-US-China)	***21.1***	***20.9***	***22.3***
…share of total (excluding bunkers)	45%	37%	39%
Total (Rest of the world)	***26.2***	***35.4***	***35.4***
…share of total (excluding bunkers)	55%	63%	61%

*Note: columns and rows may not add up due to rounding.

It should be noted that estimates of past greenhouse gas emissions by each country and globally are subject to large uncertainties. For instance, the contribution of Working Group III of the Intergovernmental Panel on Climate Change (2014) to the Fifth Assessment Report estimated that total global annual emissions of greenhouse gases in 2010 were 49±4.5 Gt CO_2e, including emissions from peat. The International Energy Agency (2014b) concluded that global annual emissions in 2010 were 49.8 Gt CO_2e, including peat emissions, but found that emissions from the 28 Member States of the European Union, United States and China were, respectively, 5.0 Gt CO_2e, 6.7 Gt CO_2e, and 10.8 Gt CO_2e.

Interpretation

In order to assess to what extent the projections from our preliminary analysis are consistent with the international agreement to avoid a rise in global mean surface temperature of more than 2°C above its pre-industrial level, we refer to the assessment published in 2014 by the United Nations Environment Programme (UNEP), which presented a synthesis of the results of published model projections available in the database assembled by Working Group III of the Intergovernmental Panel on Climate Change for the Fifth Assessment Report. UNEP (2014) categorised projections based on their assumptions about mitigation action until 2020 and about net negative carbon dioxide emissions, in order to more rapidly reduce atmospheric concentrations of greenhouse gases, through the use, for instance, of bioenergy with carbon capture and storage technology (BECCS).

It should be noted that assuming significant net negative carbon dioxide emissions during the 21st century is controversial – it may not prove to be possible. Pathways that assume net negative carbon dioxide emissions tend to assume lower levels of reductions in annual emissions before 2050, with stronger cuts (significantly enhanced by negative emissions) later in the century. However, such pathways would carry a risk of exceeding the warming limit of 2°C if net negative emissions cannot be realised.

UNEP (2014) pointed that in the case of limited global action to reduce emissions until 2020, followed by cost-optimal reductions afterwards, there are no models that offer a 50-66 per cent chance of limiting warming to less than 2°C above pre-industrial levels by 2100 without assuming net negative emissions of carbon dioxide from energy and industry during the 21st century (Table 4).

Table 4: Annual global emissions in 2030 for published model pathways that are consistent with 50-66% chance of limiting global warming to less than 2°C

Scenario	Number of model pathways	Annual emissions in 2030 (Gt CO_2e)	
		Range	Median
Limited action until 2020 and cost-optimal mitigation afterwards, no net negative carbon dioxide emissions	0	-	-
Limited action until 2020 and cost-optimal mitigation afterwards, net negative carbon dioxide emissions	4	46-48	47
Cost-optimal mitigation from 2010 onwards, no net negative carbon dioxide emissions	16	32-44	36
Cost-optimal mitigation from 2010 onwards, net negative carbon dioxide emissions	43	35-50	42

Source: UNEP (2014)

However, when the achievement of net negative emissions is assumed, four published model pathways suggest that the rise in global average temperature could be limited to less than 2°C. These pathways have a median value of 53 Gt CO_2e in 2020, reducing to 47 Gt CO_2e in 2030, 28 Gt CO_2e in 2050 and -1 GtCO_2e by 2100. The four model pathways show a range of values for global emissions in 2030 between 46 and 48 Gt CO_2e, with a median value of 47 Gt CO_2e. These totals are much lower than our projected estimates of 57 to 59 Gt CO_2e for global annual emissions in 2030.

UNEP (2014) also analysed model projections that assumed cost-optimal greenhouse gas reductions from 2010 onwards. It is arguable whether such an assumption is valid. Nevertheless, 16 projected pathways have been published which make this assumption but do not assume that net negative carbon dioxide emissions from energy and industry occur during the 21st century in order to limit global warming to less than 2°C. These pathways have median values of 37 Gt CO_2e in 2020, 36 Gt CO_2e in 2030, 27 Gt CO_2e in 2050 and 14 Gt CO_2e in 2100. The 16 model pathways show a range of values for global emissions in 2030 between 32 and 44 Gt CO_2e, with a median value of 36 Gt CO_2e. These totals are also much lower than our projected estimates of 57 to 59 Gt CO_2e for global annual emissions in 2030.

In addition, UNEP (2014) presented an analysis of published model projections that assume both cost-optimal greenhouse gas reductions from 2010 onwards, and net negative carbon dioxide emissions from energy and industry during the 21st century in order to limit global warming to less than 2°C. These 43 pathways have median values of 47 Gt CO_2e in 2020, 42 Gt CO_2e in 2030, 27 Gt CO_2e in 2050 and -2 Gt CO_2e in 2100. The model pathways show a range of values for global emissions in 2030 between 35 to 50 Gt CO_2e, with a median value of 42 Gt CO_2e. Yet again, these totals are much lower than our projected estimates of 57 to 59 Gt CO_2e for global annual emissions in 2030.

Finally, it is worth noting that UNEP (2014) also pointed out that a 'business as usual' pathway for annual global emissions of greenhouse gases would lead to between 63 and 72 Gt CO_2e in 2030. This range is considerably higher than our projected estimates of 57 to 59 Gt CO_2e for global annual emissions in 2030. Hence, the announcements and intended nationally determined contributions from the European Union, United States and China do represent progress, even if they are not consistent with the overall goal of avoiding global warming of more than 2°C.

Conclusions

Our preliminary analysis, based on the recent announcements by the European Union, United States and China, and assessments of currently implemented and planned policies around the rest of the world, suggests that the INDCs submitted to the UNFCCC secretariat in 2015 are unlikely to be consistent with the international goal of limiting the rise in global mean surface temperature to no more than 2°C, even though they represent measurable progress, if delivered, relative to a 'business as usual' emissions pathway.

Our preliminary analysis projects that the European Union, United States and China, together currently representing 2.2 billion of the global population of 7.2 billion, would collectively emit about 21 Gt CO_2e in 2030, even if China succeeds in reaching a peak in emissions in 2025. Published model projections that are consistent with a 50-66% chance of limiting global warming to less than 2°C suggest that global annual emissions should be no more than 35 to 50 Gt CO_2e in 2030, even assuming significant net negative carbon dioxide emissions from energy use during the 21st century. Based on current and planned policies as of late 2014, the rest of the world would collectively emit 35.4 Gt CO_2e in 2030, meaning global emissions would be 57 to 59 Gt CO_2e in 2030. While it is hoped that countries will include more ambitious plans for emissions reductions in their submissions of INDCs to the UNFCCC secretariat, it seems likely that there will still be a significant gap between aggregate national intentions and a pathway that is consistent with avoiding global warming of more than 2°C. Indeed, there is likely to be a very significant gap between aggregate national intentions and the projected model pathways that are lowest risk (i.e. do not depend on net negative carbon dioxide emissions during the latter half of the 21st century), which indicate that global annual emissions in 2030 would need to be between 32 and 44 Gt CO_2e.

It is important to note the uncertainties involved in making projections of future emissions, particularly because countries can very rapidly change their levels of ambition. For instance, there are indications that China's annual emissions of greenhouse gases may peak even before 2025, as its consumption of coal, a major source of carbon dioxide emissions, was 2.9% lower in 2014 compared with 2013. A recent report by the Energy Research Institute of China's National Development and Reform Commission suggested that, by 2050, it is "technically and economically feasible" that more than 85% of power needs and over 60% of energy consumption in the country could be met by renewable sources. Other countries could also significantly increase their ambitions before COP21 or soon after. Nevertheless, we believe that the overall conclusions of our analysis are robust, even allowing for uncertainties in the projected estimates.

Our preliminary estimates do not take into account further action indicated by the rest of the world in INDCs that will be submitted to the UNFCCC secretariat during 2015, and which are expected to mean further emissions reductions beyond those achieved by existing policies. Hence our estimates for global emissions in 2030 should be regarded as an upper bound, and the INDCs could collectively move the world closer to the international policy goal than our preliminary analysis indicates.

Although our analysis separates the emissions by the European Union, United States and China from the rest of the world, this is only because they have provided information about their INDCs, or what is likely to be included. This does not mean that we consider the European Union, United States and China to be primarily responsible for the discrepancy between the likely contributions and the goal of avoiding global warming of more than 2°C. All countries are collectively responsible for tackling the mismatch between aggregate national intentions and the international goal of limiting global warming to no more than 2°C. Rich countries have particular responsibilities because of their relatively high per capita emissions, both historically and currently, their current wealth, and their current development and deployment of low-carbon technologies.

The ambitions and plans agreed at the Paris summit in December 2015 should be regarded as a critical initial step. It is also important that countries make pledges that are credible. However, the magnitude of the gap between current intentions and the international target of limiting global warming to no more than 2°C clearly shows that an international agreement in Paris will have to include dynamic mechanisms for the assessment of progress and the raising of ambitions. Hence the Paris summit should not be regarded as just a one-off opportunity to fix targets.

The gap identified by our preliminary analysis between aggregate intended contributions and the goal of limiting global warming to no more than 2°C above its pre-industrial level could be addressed through at least four courses of action:

i) hard work over the next few months by all countries to find credible ways of achieving bigger emissions reductions which can be included in INDCs to be submitted to the UNFCCC secretariat, and/or achieved through additional efforts by partnerships (e.g. through specific decarbonisation initiatives among willing countries);

ii) an intensification of efforts to increase investment and innovation, particularly in relation to the development of cities, energy systems and land use, that could help to close the gap between intentions and the goal before and after 2030;

iii) the creation of a mechanism, to be included in the agreement emerging from COP21 in Paris in December 2015, for countries to

review their efforts and to find ways of ramping up the ambition of their emissions reductions by 2030 and beyond; and

iv) concerted efforts by all countries to build strong and transparent domestic bases for the implementation of their INDCs, setting countries on a path to decarbonisation and enabling them to ramp up their ambitions.

The intended contributions put forward by developing countries before COP21 will depend on the extent to which they have confidence that the rich countries will share technologies and provide financial support for the transition to a low-carbon economy. Rich countries also have an opportunity after COP21 to offer such backing for greater ambition by developing countries.

Hence, the INDCs that are submitted in 2015 should be regarded as the starting point, rather than the end point, of what will be delivered by each country. The period following the summit in Paris in December 2015 will be crucial, not just to bridge the gap in 2030 between aggregate intentions and the goal, but also to lay the foundations for even greater action after 2030.

The INDCs put forward by countries in 2015 should be assessed not just on whether they are consistent with the goal of avoiding global warming of more than 2°C, but also on their credibility. In this context, it is also important to note that the contributions and other announcements made by the European Union, United States and China are based on the implementation of existing or planned domestic policies. They have also established legal and administrative structures to deliver their plans, including decisions of the European Council, the powers of the United States Environmental Protection Agency, and China's five-year plans. And they are on target to meet the commitments they made at COP15 in 2009 and COP16 in 2010 to limit their emissions by 2020. For all these reasons, the post-2020 contributions and other announcements made by the European Union, United States and China should be regarded as more credible than they would be in the absence of these factors.

Appendix: Details of method

European Union (28 Member States)

On 23 October 2014, the European Council (2014) endorsed a binding collective target for the 28 Member States of the European Union of "at least 40% domestic reduction in greenhouse gas emissions by 2030 compared to 1990". This was confirmed in the submission in March 2015 to the secretariat of the UNFCCC of the 'Intended Nationally Determined Contribution of the EU and its Member States'.

In order to estimate annual emissions of the basket of six anthropogenic greenhouse gases covered by the Kyoto Protocol for the European Union in 2030, we note that, according to figures published by the European Environment Agency (2014) for the period between 1990 and 2012 (which also correspond to the figures published by the UNFCCC in its database of national greenhouse gas inventories), collective annual emissions (including land use, land use change and forestry, but not peat) for the 28 Member States were 5.4 Gt CO_2e in 1990. The Member States have already committed to reducing their collective domestic emissions by 20% to 4.3 Gt CO_2e by 2020 compared with 1990 levels. If the collective emissions of the 28 Member States in 2030 are 40% lower than in 1990, they would be about 3.2 Gt CO_2e. The emissions pathway between 1990 and 2030 assumed by our analysis for the European Union is illustrated in Figure 1.

United States

On 12 November 2014, President Barack Obama and President Xi Jinping released a 'U.S.-China Joint Announcement on Climate Change' (Office of the White House Press Secretary, 2014), which stated: "The United States intends to achieve an economy-wide target of reducing its emissions by 26%–28% below its 2005 level in 2025 and to make best efforts to reduce its emissions by 28%". This was confirmed in the submission in March 2015 to the secretariat of the UNFCCC of its intended nationally determined contribution.

In order to estimate annual emissions of the basket of six anthropogenic greenhouse gases covered by the Kyoto Protocol for the United States in 2030, we note that, according to figures published by the Environmental Protection Agency (2014) for the period between 1990 and 2012 (which also correspond to the figures published by the UNFCCC in its database of national greenhouse gas inventories), annual emissions (including land use, land use change and forestry, but not peat) for the United States were 6.2 Gt CO_2e in 2005. If the annual emissions of the United States in 2025 are 28% lower than in 2005, they would

be about 4.5 Gt CO_2e. To estimate emissions in 2030, we note the fact sheet on the 'U.S.-China Joint Announcement on Climate Change and Clean Energy Cooperation', published on 11 November 2014 by the White House, which stated that the 2025 target "will keep the United States on the right trajectory to achieve deep economy-wide reductions on the order of 80 percent by 2050". Hence we extrapolate linearly from the annual emissions of 4.5 Gt CO_2e in 2025 to 1.2 Gt CO_2e (ie 80% lower than in 2005) in 2050, and obtain a figure of 3.8 GtCO_2e in 2030. The emissions pathway between 1990 and 2030 assumed by our analysis for the United States is illustrated in Figure 1.

China

On 12 November 2014, President Barack Obama and President Xi Jinping released a 'U.S.-China Joint Announcement on Climate Change' (Office of the White House Press Secretary, 2014) which stated that "China intends to achieve the peaking of CO_2 emissions around 2030 and to make best efforts to peak early and intends to increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030".

In order to estimate annual emissions of the basket of six anthropogenic greenhouse gases covered by the Kyoto Protocol for China in 2030, we began by obtaining annual emissions (including land use, land use change and forestry) for the period between 1990 and 2010 from the database of the International Energy Agency (2015). There are only limited data for greenhouse gas emissions by China since 2010. We have used estimates of China's carbon dioxide emissions from energy use in 2011 and 2012, which were published by the International Energy Agency in its World Energy Outlook in 2013 and 2014, and assumed that the ratio of other greenhouse gases to carbon dioxide during those years was the same as in 2010 in order to estimate total greenhouse gas emissions. We note that the rate of growth in annual emissions in the period since 2010 may have decreased significantly after 2012. Figures published by the National Bureau of Statistics of China in February 2015 indicated that consumption of coal, a major source of carbon dioxide emissions, was 2.9% lower in China in 2014 compared with 2013. However, we have estimated China's emissions between 2013 and 2030 by making the simple assumption of linear reductions in the annual growth rates of emissions, reaching 0% growth in 2025 or 2030. If China's emissions peak in 2025, we estimate that its emissions in 2030 will be 13.8 Gt CO_2e. If China's emissions peak in 2030, we estimate that its emissions in 2030 will be 15.3 GtCO_2e. The emissions pathway between 1990 and 2030 assumed by our analysis for China is illustrated in Figure 1.

Rest of the world

In order to estimate annual emissions of the basket of six anthropogenic greenhouse gases covered by the Kyoto Protocol for the rest of the world (i.e. not including the 28 Member States of the European Union, United States and China) in 2030, we began by obtaining annual emissions (including land use, land use change and forestry, including peat) for the period between 1990 and 2010 from the database of the International Energy Agency (2015). In order to estimate emissions beyond 2010, we calculated the rate of change in carbon dioxide emissions from energy use published by the International Energy Agency in its 'World Energy Outlook 2014', based on the 'New Policies Scenario' (i.e. taking into account "policies and implementing measures affecting energy markets that had been adopted as of mid-2014, together with relevant policy proposals, even though specific measures needed to put them into effect have yet to be fully developed…This broadly serves as the IEA baseline scenario."[3]). It is important to note that these do not take into account the intended nationally determined contributions that were submitted by Switzerland, Norway, Mexico, Gabon, Russia and Liechtenstein to the secretariat of the UNFCCC by 30 April 2015.

We used the following regions in our analysis of the rest of the world:

- Africa
- Brazil
- India
- Asia (without China, India)
- OECD Asia Oceania
- Non-OECD Americas (without Brazil)
- OECD Americas (without US)
- Non-EU 28 Europe (including non-EU 28 OECD, non-OECD Europe/Eurasia)
- Middle East

In order to obtain estimates of total annual greenhouse gas emissions, we extrapolated the figures for 2010 to 2030 using the growth rates calculated from the New Policies Scenario for carbon dioxide emissions from energy use.

[3] From IEA (2014). This broadly serves as the IEA baseline scenario. For full details of policies and measures assumed in the IEA scenarios, see Annex B of IEA (2014; pp 687–698).

References

European Council, 2014. *European Council (23 and 24 October 2014): Conclusions on 2030 Climate and Energy Policy Framework*. Brussels, Belgium. Available at: http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/145356.pdf

European Environment Agency, 2014. *Annual European Union greenhouse gas inventory 1990–2012 and inventory report 2014 (Submission to the UNFCCC Secretariat) – Technical Report 09/2014*. Brussels, Belgium. Available at: http://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2014

Environmental Protection Agency, 2014. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2012 (April 2014)*. Washington DC, United States of America. Available at: http://www.epa.gov/climatechange/ghgemissions/usinventoryreport/2014.html

Intergovernmental Panel on Climate Change, 2014. *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Available at: http://www.ipcc.ch/report/ar5/wg3/

International Energy Agency, 2012. *World Energy Outlook 2012*. IEA/OECD, Paris, France. Available at: http://www.worldenergyoutlook.org/

International Energy Agency, 2013. *World Energy Outlook 2013*. IEA/OECD, Paris, France. Available at: http://www.worldenergyoutlook.org/

International Energy Agency, 2014a. *World Energy Outlook 2014*. IEA/OECD, Paris, France. Available at: http://www.worldenergyoutlook.org/

International Energy Agency, 2014b. *CO_2 Emissions from Fuel Combustion (2014 Edition)*. Available at: http://www.iea.org/bookshop/648-CO2_Emissions_from_Fuel_Combustion

International Energy Agency, 2015. Emissions database. IEA/OECD, Paris, France. Available at: http://data.iea.org/

National Bureau of Statistics of China, 2015. *Statistical Communiqué of the People's Republic of China on the 2014 National Economic and Social Development*.

Beijing, China. Available at: http://www.stats.gov.cn/english/PressRelease/201502/t20150228_687439.html

Office of the White House Press Secretary, 2014. *U.S.-China Joint Announcement on Climate Change*. Washington DC, United States of America. Available at: http://www.whitehouse.gov/the-press-office/2014/11/11/us-china-joint-announcement-climate-change

United Nations Environment Programme, 2014. *The Emissions Gap Report 2014*. Nairobi, Kenya. Available at: http://www.unep.org/publications/ebooks/emissionsgapreport2014/portals/50268/pdf/EGR2014_LOWRES.pdf

United Nations Framework Convention on Climate Change, 2011. Report of the Conference of the Parties on its sixteenth session, held in Cancún from 29 November to 10 December 2010. Addendum Part Two: Action taken by the Conference of the Parties at its sixteenth session. Bonn, Germany. Available at: http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf

White House, 2014. Fact Sheet: U.S.-China Joint Announcement on Climate Change and Clean Energy Cooperation. Washington DC, United States of America. Available at: http://www.whitehouse.gov/the-press-office/2014/11/11/fact-sheet-us-china-joint-announcement-climate-change-and-clean-energy-c